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14. ABSTRACT A new air purification technology (SELEX) was developed and demonstrated. The SELEX system utilizes an array of electrospray wick aerosol sources for particle ionization and an electrostatic precipitator for particle collection. The particle ionization process does not produce ozone and the SELEX technology provides a unique combination of very low pressure drop, high collection efficiency and low power. A 50 cfm breadboard prototype (SELEX II) was developed and, in addition to particle collection, incorporates the ability to inactivate collected live organisms					
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- Final Report -

The SELEX air Purification System

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Objectives and Tasks (from SoW):

Years 1 & 2 (10/2006 – 9/2008)

Objective:

- The development of a zero pressure drop air purification technology, which utilizes charged nanodroplets produced by electrospray. The resulting SELEX device will have the following features: negligible pressure drop, high collection efficiency for both bacterial and chemical agents, low consumable and waste generation and very low power. SELEX is the “SElective ionization and contaminant EXtraction system.

Task 1: SELEX I Design	Completed
Task 2: SELEX I Construction	Completed
Task 3: SELEX I Parametric Testing	Completed
Task 4: SELEX II Design	Completed

Year 3 (10/2008-11/2009)

Objective:

- A breadboard prototype of the SELEX-II zero pressure drop air purification technology will be developed and tested against viable microbial aerosols. The breadboard prototype will be designed to achieve 99% (threshold) and 99.9% (objective) purification efficiency for airborne particles and live organisms at an air flow rate of 50 cfm and will incorporate a biocidal photocatalytic oxidation component to convert all collected organisms into environmentally safe products.

Task 5: SELEX II Biocidal Component Dev.	Completed
Task 6: SELEX II Breadboard Development	Completed
Task 7: SELEX II Breadboard Testing	Completed

All Project Tasks Have Been Successfully Completed

Detailed Summary of Work by Task

Task 1: SELEX I Design

Several different designs of the SELEX I system were produced, constructed and tested including a small, coaxial flow design (figure 1), a cylindrical design (figure 2) and a parallel plate design (figure 3). The parallel plate design provided the best overall performance and was selected for continued development and testing.

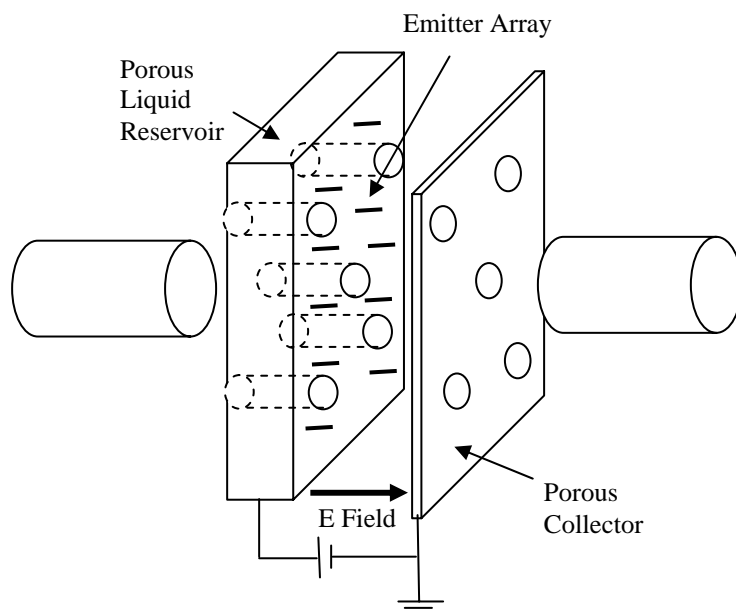


Figure 1: Schematic of coaxial flow SELEX I system design

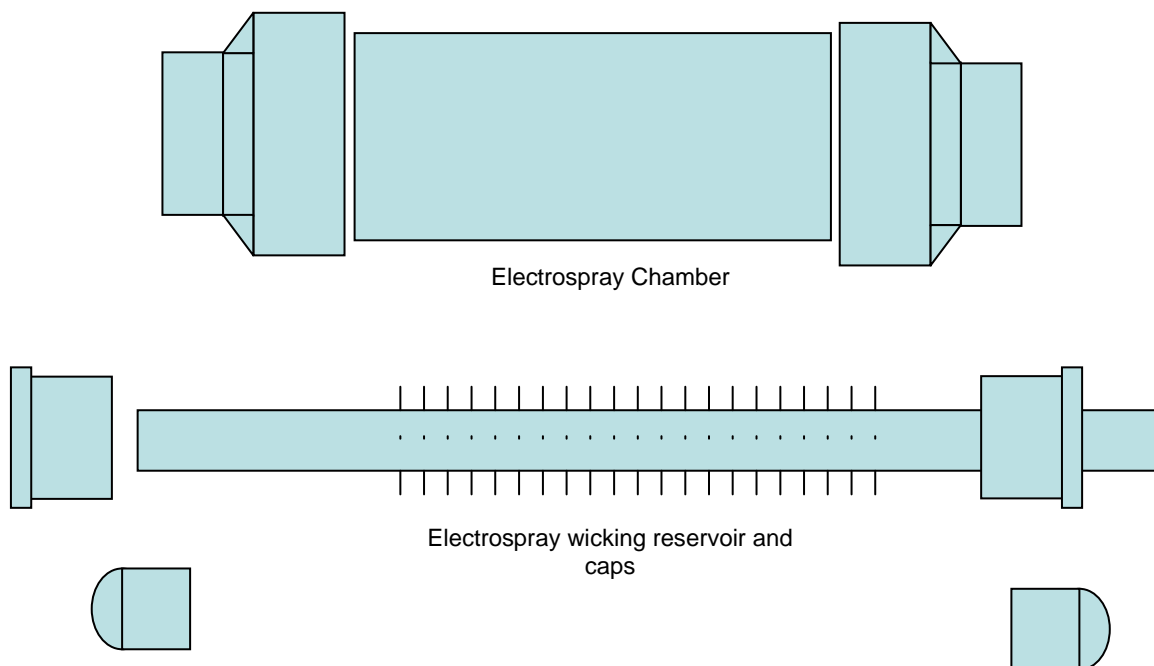


Figure 2: Schematic of cylindrical SELEX I design

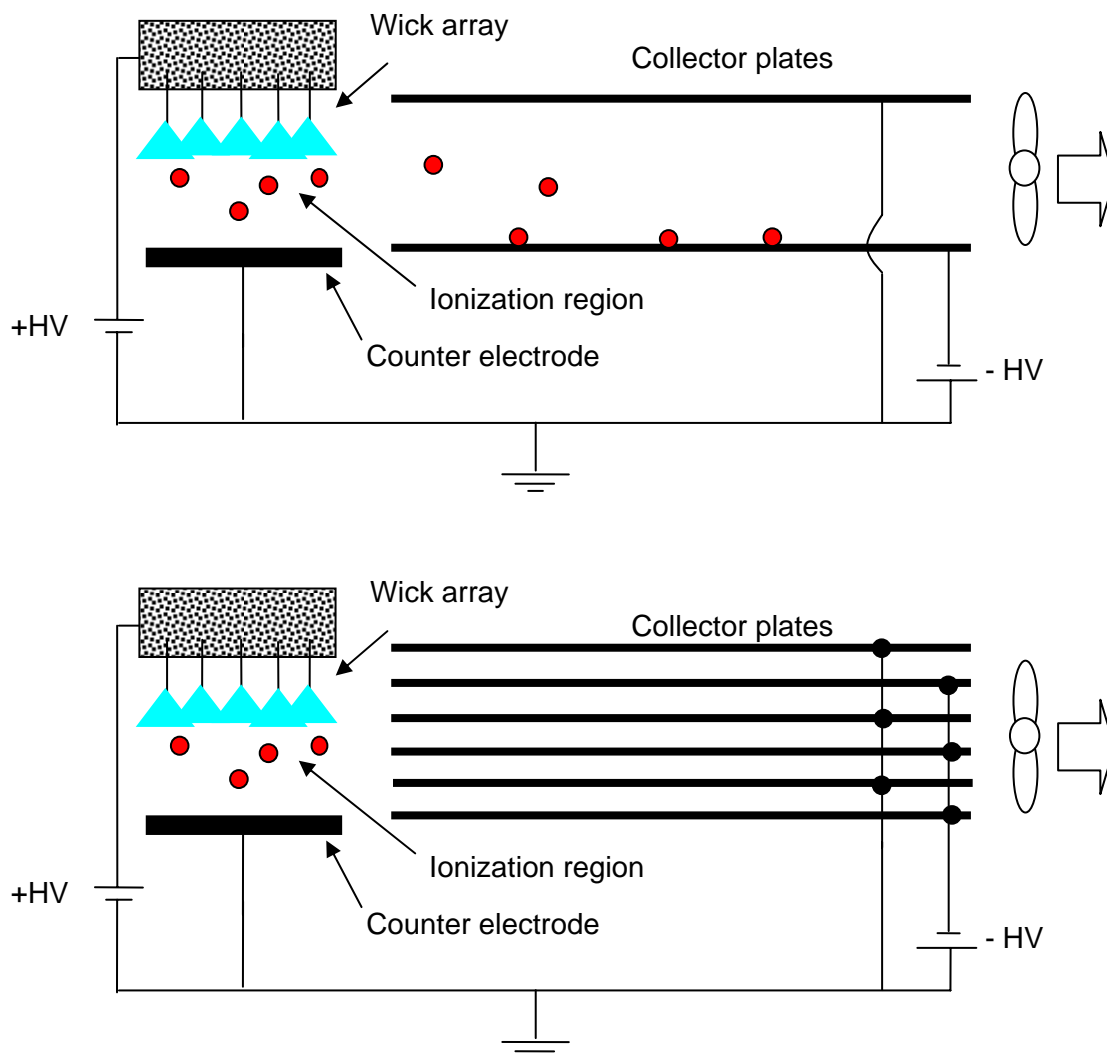


Figure 3: Schematic diagrams of parallel plate SELEX I designs

The SELEX I designs all include an array of electrospray wick sources for particle ionization and a metal surface or multiple metal surfaces for particle collection. Figure 4 is a photograph of typical electrospray wick sources (1mm and 2mm diameters). The results in this report will focus primarily on the parallel plate SELEX I device shown schematically in figure 3 since this device was the most successful and was the basis for the SELEX II system.

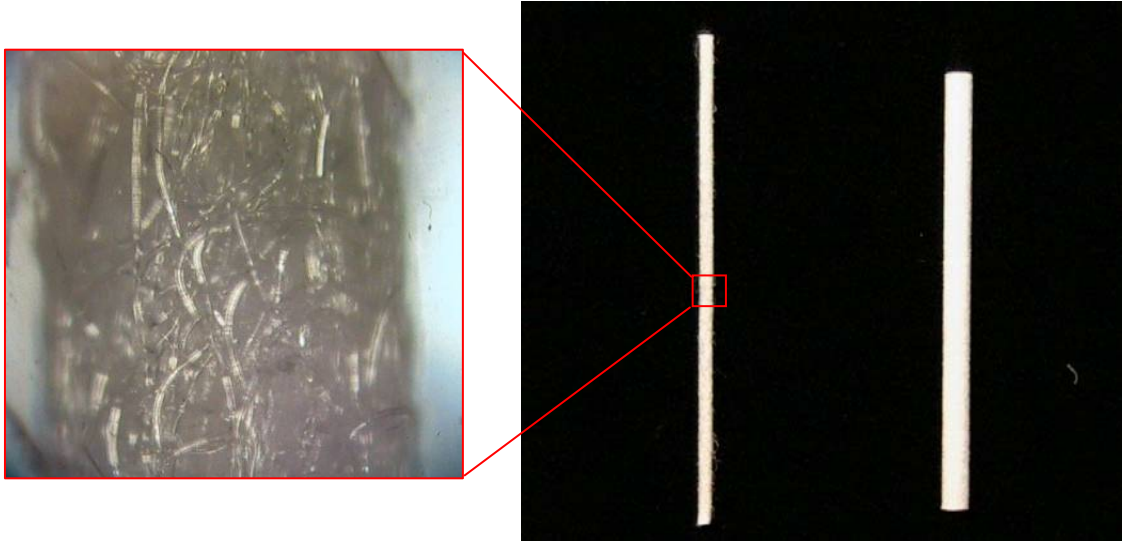


Figure 4: Photograph of electrospray wick sources (1mm and 2mm diameter)

Task 2: SELEX I Construction

The SELEX I designs from task 1 were constructed and are illustrated in figures 5 – 9. Figure 5 is a photograph of the main components of the small coaxial flow system. Figure 6 is a photograph of the fully-assembled cylindrical system. Figure 7 is a photograph of the small parallel plate system and figures 8 and 9 show elements of the large parallel plate SELEX I system. The SELEX I laboratory prototypes were used to perform detailed parametric testing (Task 3). The parametric testing results summarized in this report will focus on the parallel plate systems since this testing formed the basis of the SELEX II system.

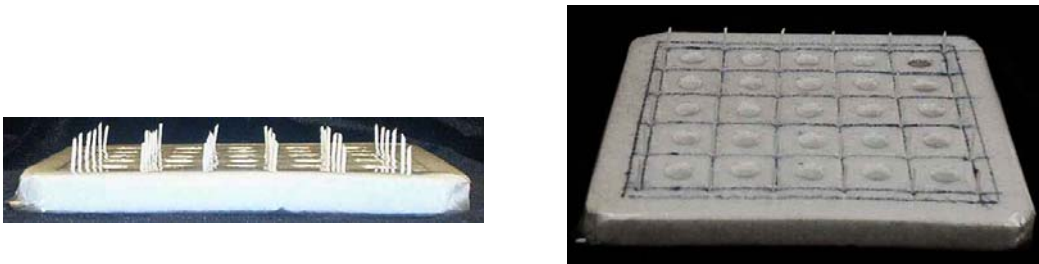


Figure 5: Photograph of main components of SELEX I coaxial flow system



Figure 6: Photograph of SELEX I cylindrical prototype

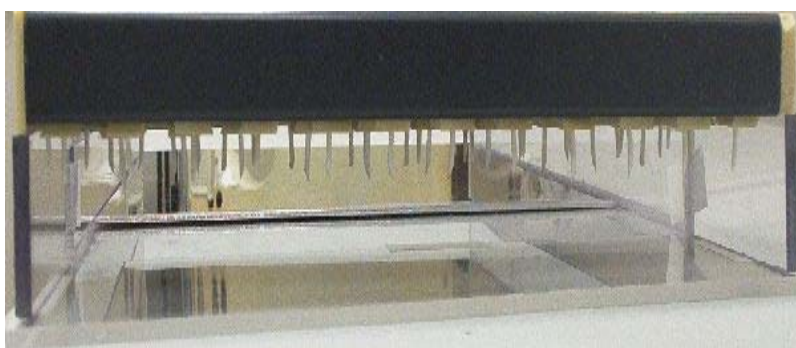


Figure 7: Photograph of small parallel plate SELEX I system

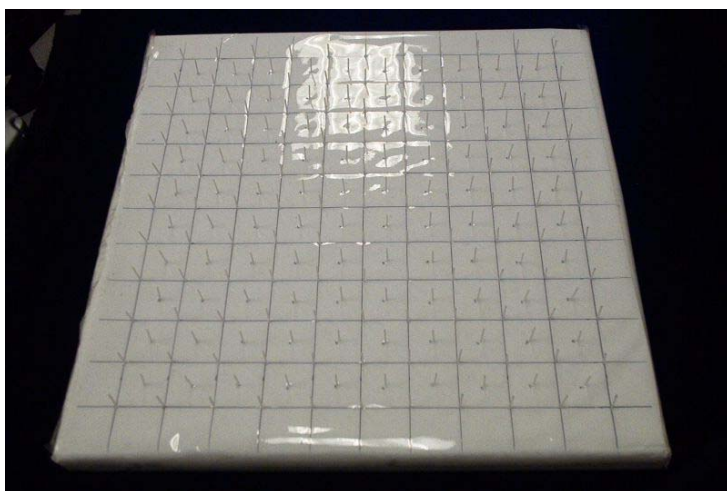


Figure 8: Photograph of electrospray array for the large SELEX I system



Figure 9: Photograph of ionization region in large SELEX I device.

Task 3: SELEX I Parametric Testing

Detailed parametric testing was performed in order to develop a fundamental understanding of the SELEX technology and the key operational requirements for efficient particle ionization and collection. Figure 10 is a plot of the particle collection efficiency for 0.3, 0.5 and 5 micron diameter particles versus the collector plate voltage for the small parallel plate device shown in figure 7. This data was used to determine the average electrical mobility of the particles and the amount of charge deposited onto the particles in the electrospray region. The following table shows the experimentally measured electrical mobility and the amount of deposited charge onto three different particle sizes. The amount of deposited charge was determined by equating the experimental mobility data to the theoretical mobility and solving for the charge.

<u>Size</u>	<u>Mobility: $\{Z_{ex} = v_{min}/E\}$</u>	<u>Charge</u>
5 micron	$Z = 1 \times 10^{-4} \text{ cm}^2/\text{V-s}$	53
0.5 micron	$Z = 7 \times 10^{-5} \text{ cm}^2/\text{V-s}$	4
0.3 micron	$Z = 6 \times 10^{-5} \text{ cm}^2/\text{V-s}$	2

The parametric testing revealed that there is a minimum electrical mobility corresponding to the largest particle which picks up a single unit of charge. We estimate that this minimum mobility occurs at a particle size near 0.2 microns. Figure 11 is a plot of the normalized theoretical electrical mobility versus the particle size.

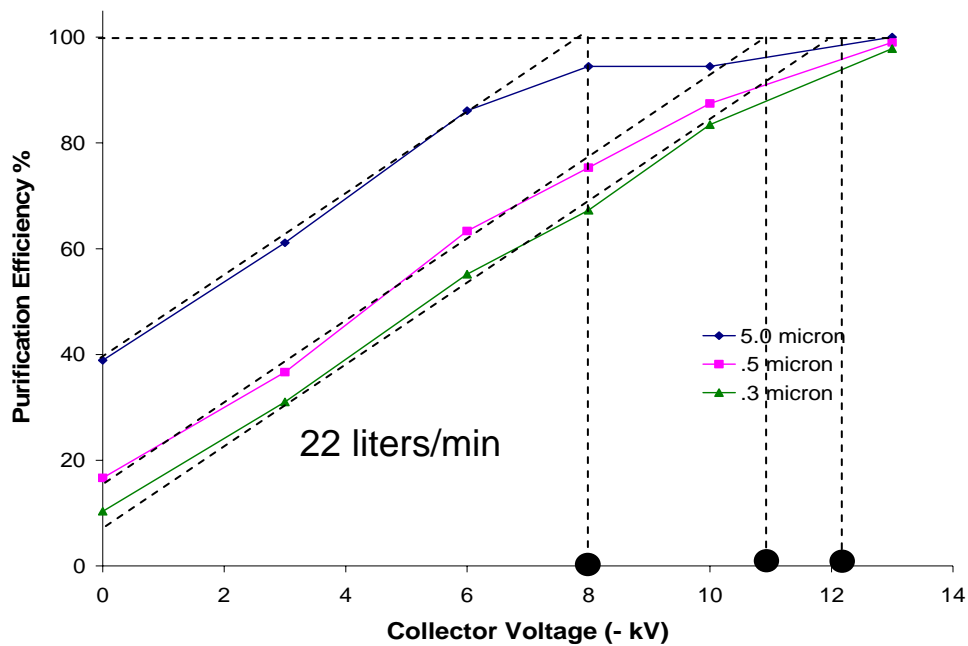


Figure 10: Purification efficiency versus collector plate voltage in small parallel plate SELEX I device (air flow rate = 22 l/m)

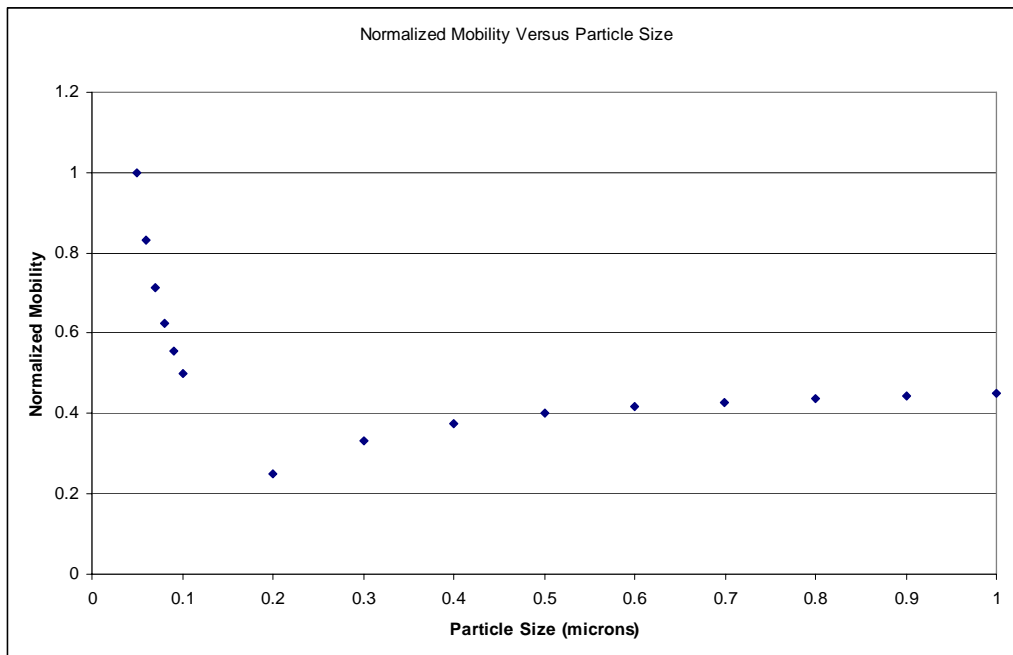


Figure 11: Normalized electrical mobility versus the particle size

The air purification efficiency was measured in the large parallel plate SELEX I system shown in figure 9 as a function of air flow rate and electro spray current. Figure 12 is a plot of the air purification efficiency versus the air flow rate (top) and versus the electro spray current (bottom)

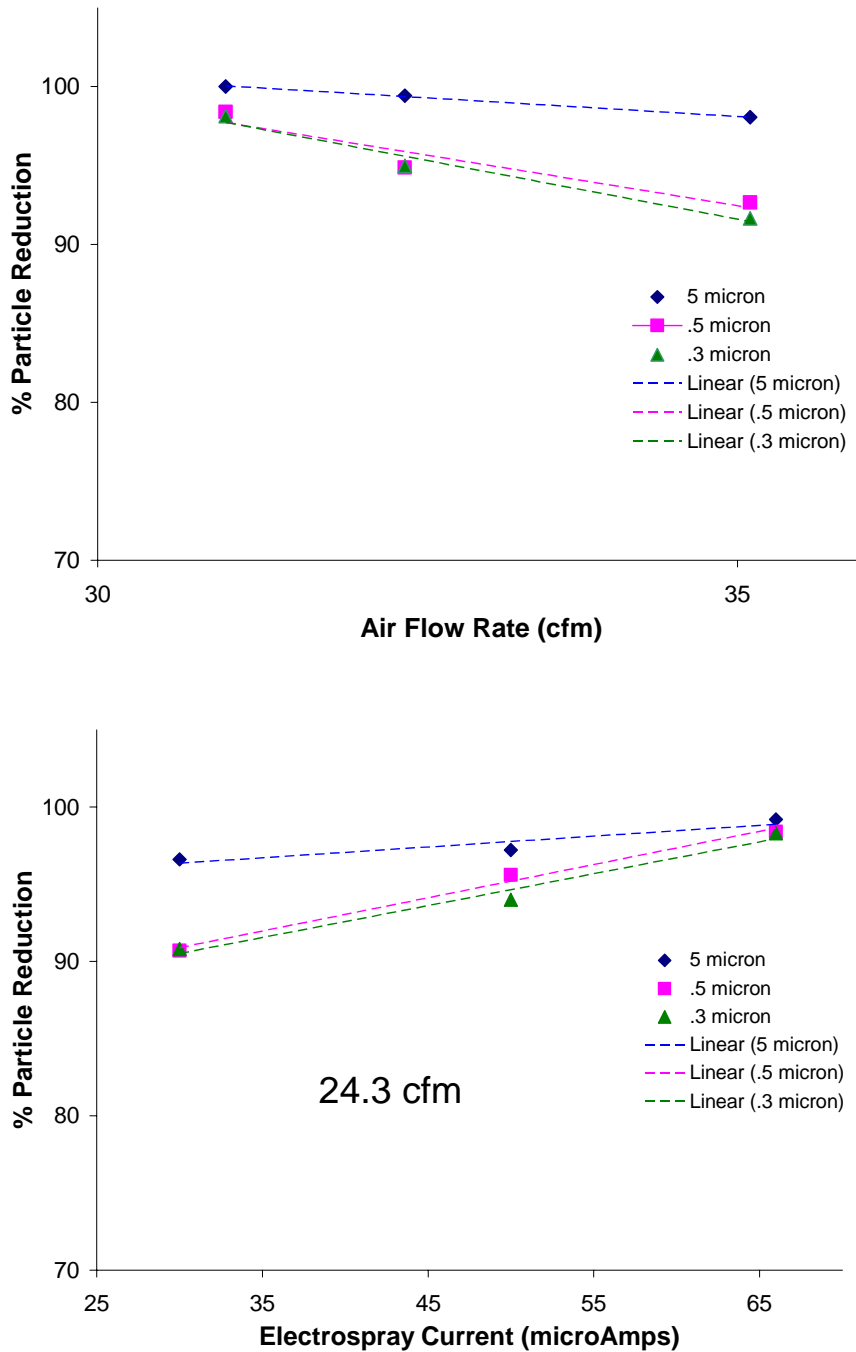
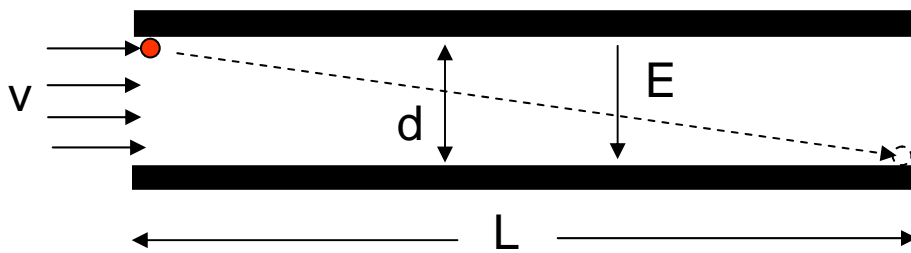


Figure 12: Air purification efficiency versus air flow rate (top) and versus electro spray current (bottom).

The parametric testing results described above were used to establish specific design requirements for the SELEX II system. The SELEX II system is a 50cfm breadboard prototype with a targeted air purification efficiency >99%.

Task 4: SELEX II Design

The collector plate was designed to collect 100% of the particles with the lowest electrical mobility (i.e. 0.2 micron particles). Figure 13 is a schematic illustrating the primary design requirement for the collection plates in the SELEX II system.



$$\text{Require: } dv/LE < Z_{\min}$$

Figure 13: Schematic diagram illustrating the design requirement for 100% particle collection efficiency.

The parametric testing results were also used to establish the minimum amount of electrospray current required to achieve the desired air purification efficiency. Figure 14 is a plot of the minimum electrospray current required to achieve 90%, 95% and 99% efficiency as a function of air flow rate. As the air flow rate is increased the minimum electrospray current increases linearly and at 50cfm is approximately 100 microamps. Therefore 100 microamps was used as the target electrospray current in the SELEX II system design.

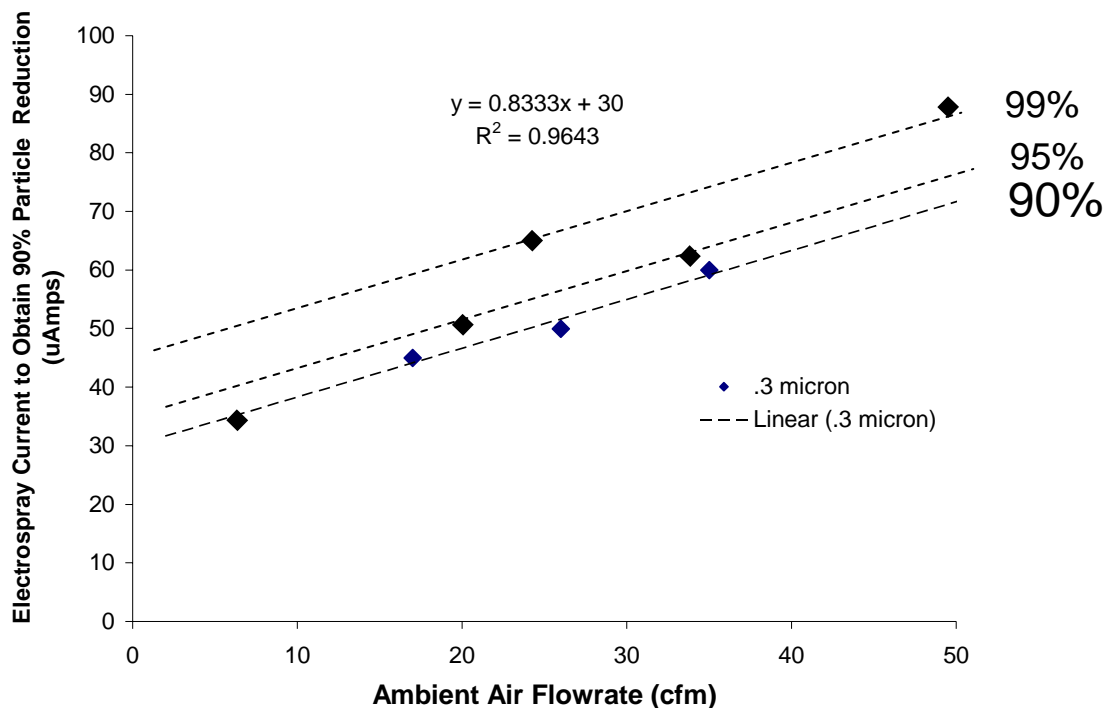


Figure 14: Minimum electro spray current required to achieve 90%, 95% and 99% efficiency as a function of air flow rate

Task 5: SELEX II Biocidal Component Development

The SELEX II breadboard prototype was designed to incorporate a biocidal component. The biocidal component consists of a photocatalytic coating applied to the collection plates and germicidal UV lamps for photoinitiation. The objective is to convert collected live organisms into harmless species with very high efficiency. Figure 15 is a photograph of a germicidal lamp with a peak output wavelength of 254 nm (mercury line).



Figure 15: Photograph of germicidal lamp used for photoactivation in the SELEX II system.

Titanium dioxide (anatase) was used as the photocatalytic coating and a protocol was developed for applying the TiO₂ coating onto the metal collection plates. Figure 16 is a photograph of a metal collection plate with a TiO₂ layer.



Figure 16: Photograph of a metal collection plate coated with a photocatalytic layer.

Task 6: SELEX II Breadboard Development

A breadboard prototype of the SELEX II system was developed and constructed based on the results of tasks 1-5. Figures 17-20 show schematic diagrams of the main components of the SELEX II breadboard prototype. SELEX II is a duct-size prototype ozone-free 50cfm air purification system.

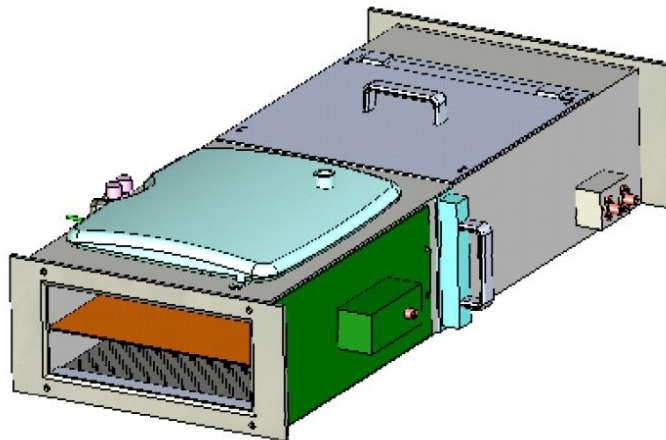


Figure 17: Solid Works drawing of SELEX II Breadboard prototype

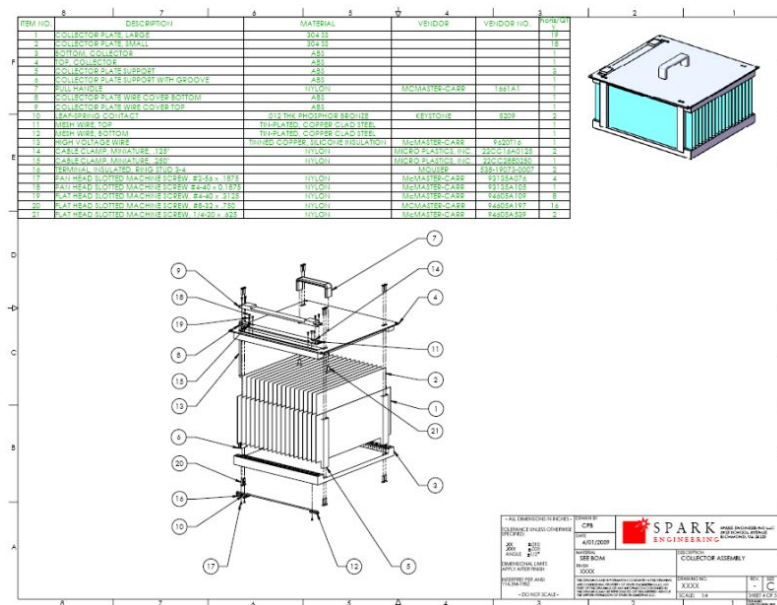


Figure 20: Schematic diagram of particle collection module

Figures 21-26 show photographs of the main components of the SELEX II breadboard prototype system.

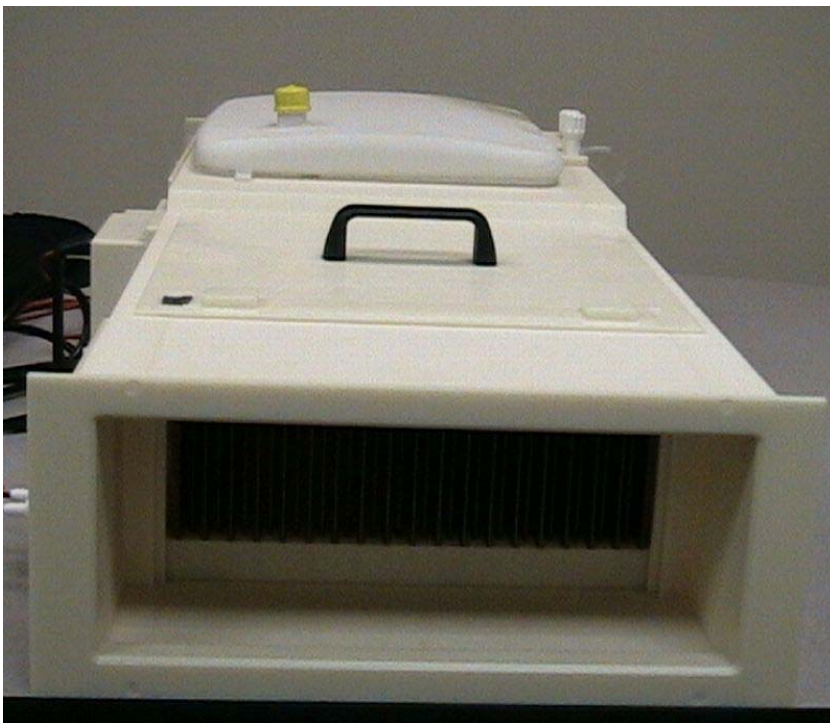


Figure 21: Downstream end of SELEX II prototype

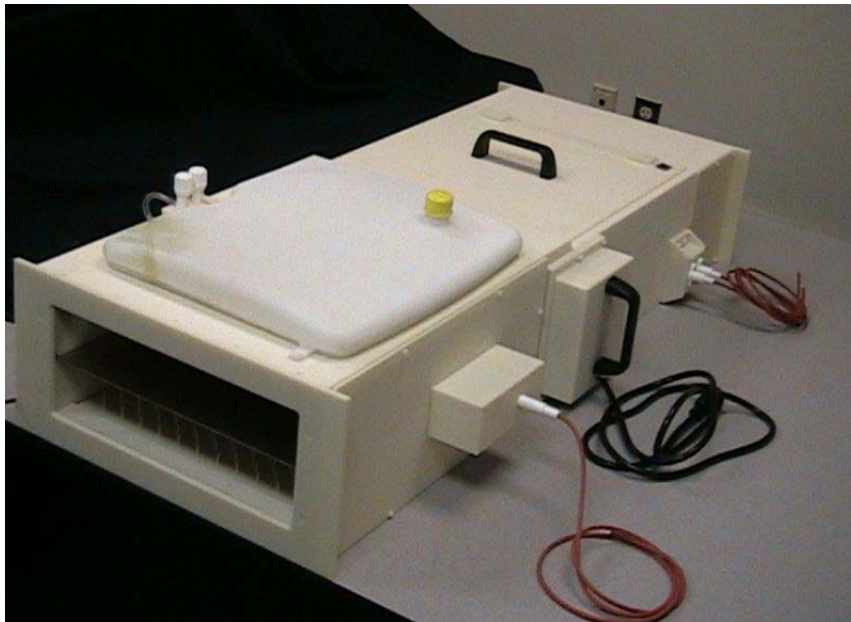


Figure 22: Side view of SELEX II system showing electrical connections

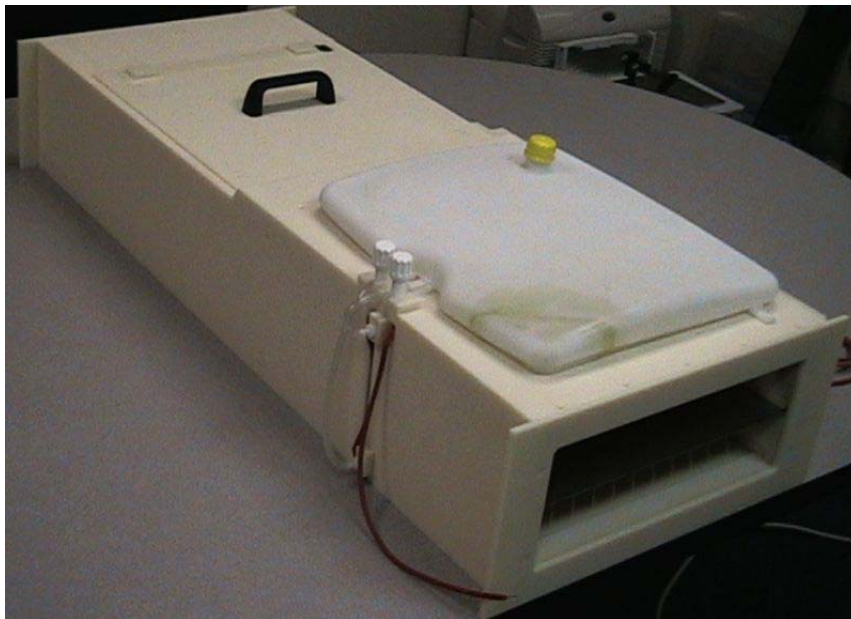


Figure 23: Side view of SELEX II system showing liquid fill system



Figure 24: Photograph of removable particle collection module



Figure 25: Photograph of SELEX II inlet showing germicidal lamps.

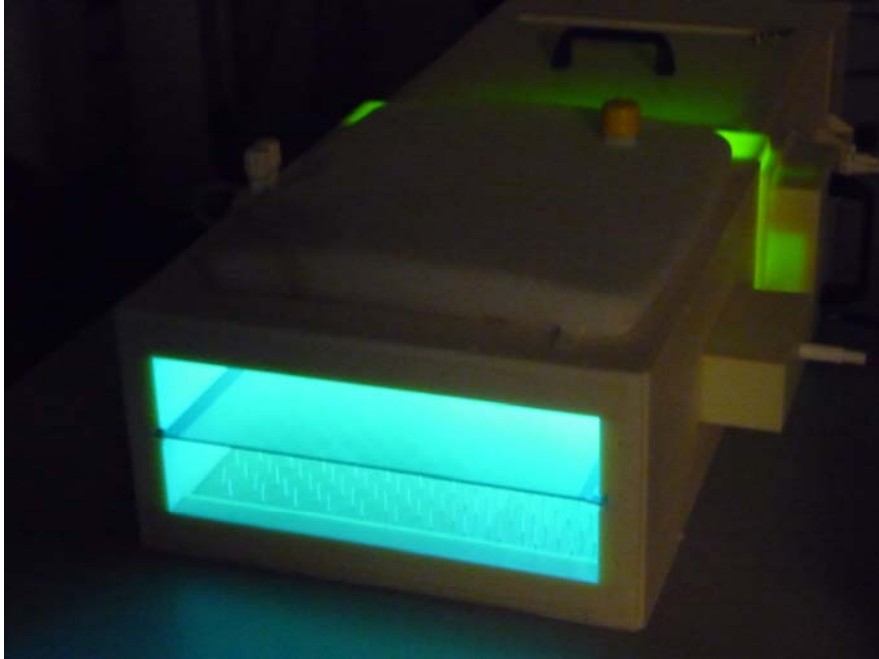


Figure 26: Photograph of SELEX II system with germicidal lamps on.

Task 7: SELEX II Breadboard Testing

Key performance parameters (e.g. air purification efficiency, energy consumption, liquid consumption) of the SELEX II breadboard prototype were tested. Figure 27 is a photograph of the ionization region with the electrospray aerosols turned on. Taylor cones are clearly visible at the tip of each wick source.

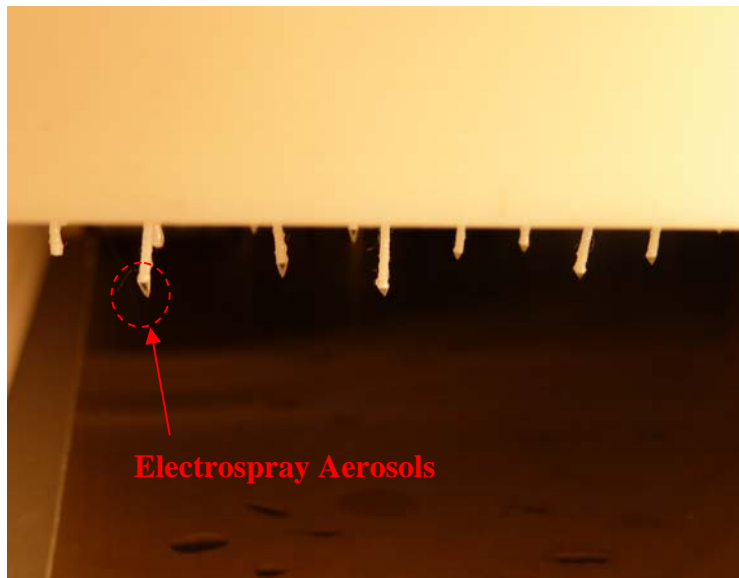


Figure 27: Photograph of electrospray aerosols in SELEX II system

Figures 28 and 29 show the electrospray current as a function of applied voltage for the SELEX II system. The electrospray solvent in figure 28 was water with 0.5% ALS surfactant and the solvent in figure 29 was water with 1% ALS surfactant. The electrospray current increased with increasing voltage and surfactant concentration.

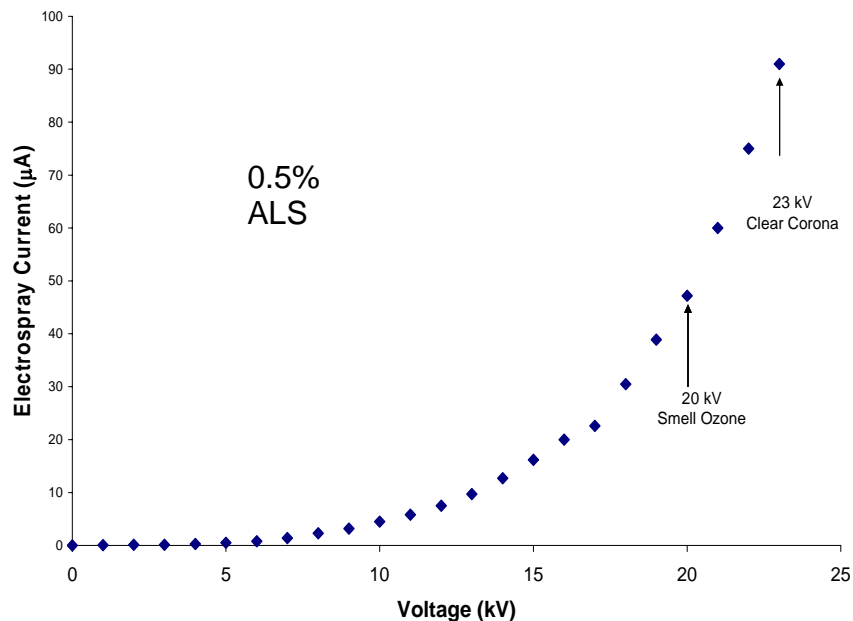


Figure 28: Electrospray current versus voltage for 0.5% ALS in water

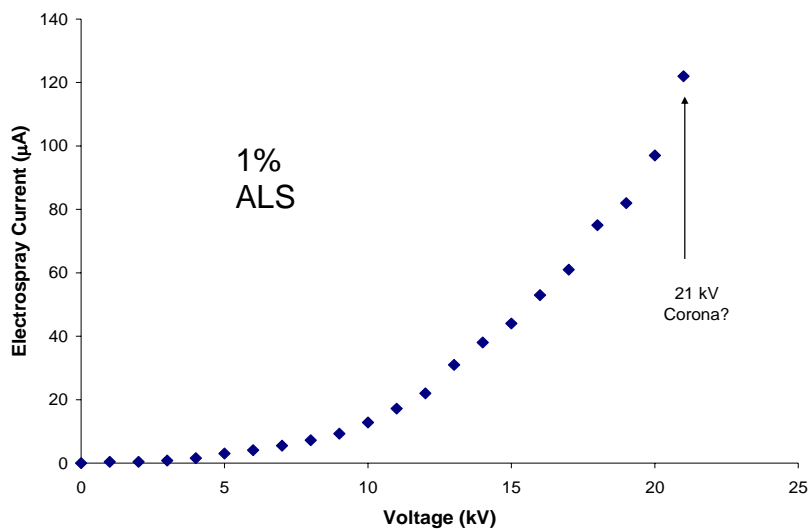


Figure 29: Electrospray current versus voltage for 1% ALS in water

Figures 30 and 31 show the particle collection efficiency in the SELEX II breadboard prototype as a function of air flow rate. Figure 30 is for the 0.5% ALS solution and figure 31 is for the 1% ALS solution. Based on this data we conclude that the efficiency of the SELEX II system exceeds 99% @50cfm for the 1% ALS solution.

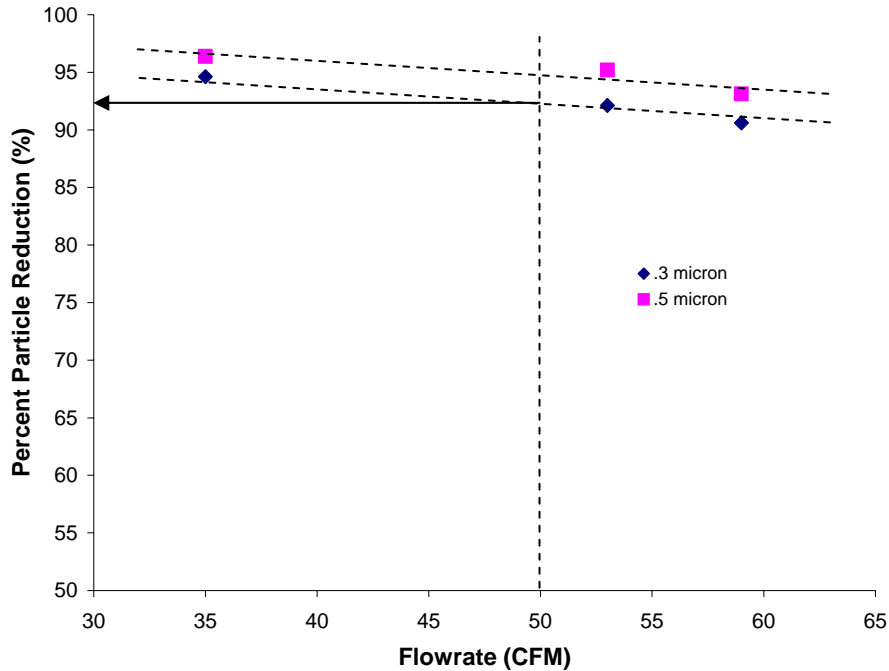


Figure 30: Air purification efficiency versus air flow rate (0.5% ALS solution)

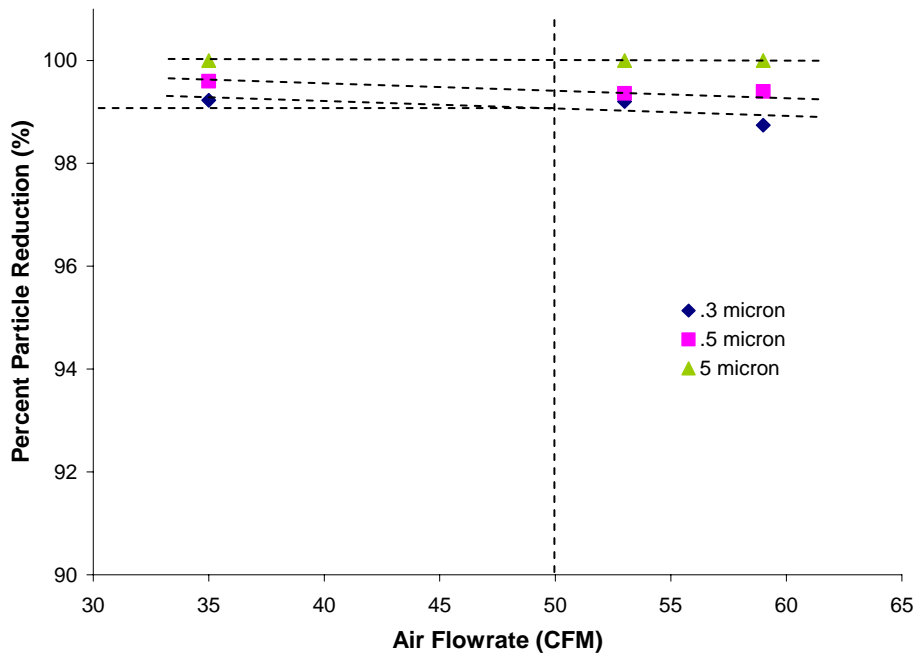


Figure 31: Air purification efficiency versus air flow rate (1% ALS solution)

Biocidal testing was performed at RTI international. The SELEX II system was tested against Bg singlets and agglomerates and the MS2 virus. Figure 32 is a histogram of the Bg particle size distribution used in this testing.

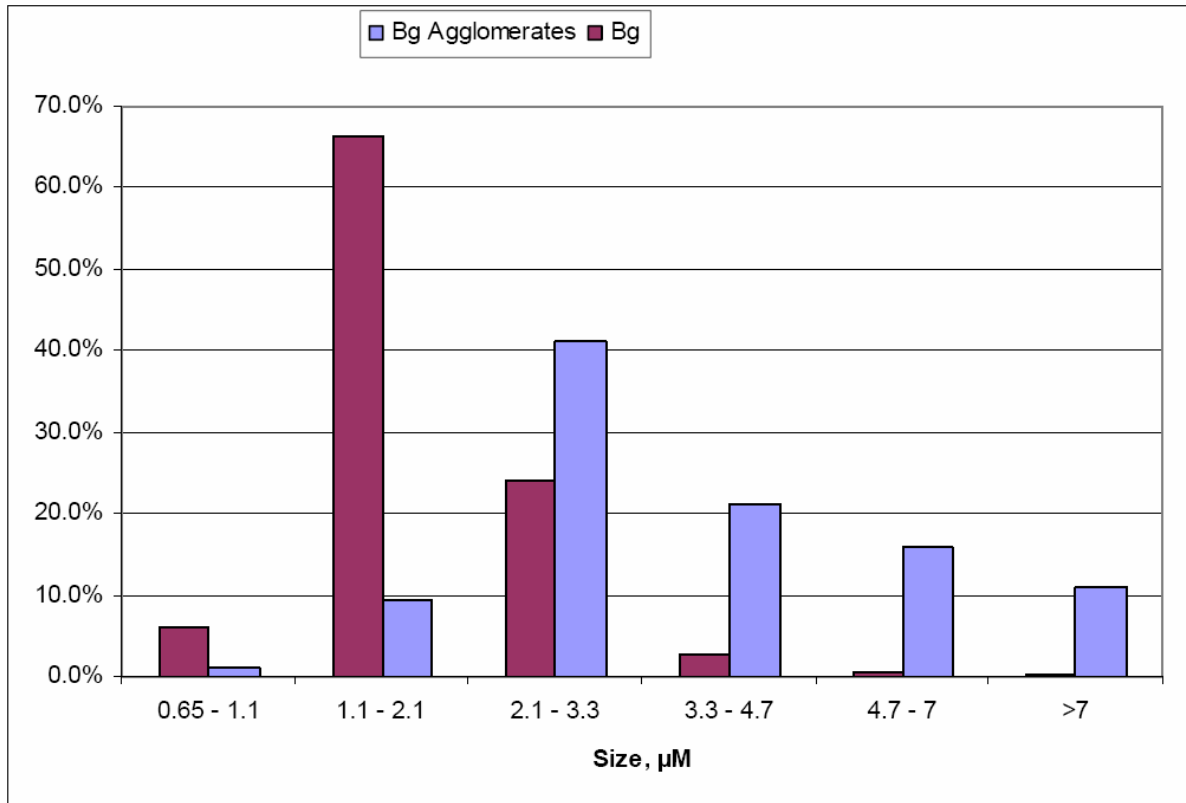


Figure 32: Histogram of Bg size distribution

Figure 33 is a chart showing the results of the SELEX II airborne purification efficiency for the Bg singlets and agglomerates as well as the MS2 virus for three different runs. The collection efficiency in these runs was slightly below optimum but this was attributed to variations in the electro spray current with time.

Bioaerosol Challenge	Size range as aerosolized (µm)	Run	Airborne Purification Efficiency (%)
<i>B. atrophaeus</i> (Bg) (Spore as singlets)	Single organisms, 0.7 - 0.8 x 1 - 1.5 µm.	1	74.5
		2	77.6
		3	84.2
<i>B. atrophaeus</i> (Bg) (Spore as agglomerates)	Agglomerated polydisperse bioaerosol of multiple organisms per particle.	1	95.3
		2	94.7
		3	91.3
MS2 virus (Bacteriophage/ bacterial virus)	Generated as polydispersed micron and submicron-sized aerosol.	1	90.0
		2	94.6
		3	92.8

Figure 33: Chart showing the results of the SELEX II airborne purification efficiency for the Bg singlets and agglomerates as well as the MS2 virus for three different runs.

Figure 34 is a chart showing the surface inactivation efficiency for the SELEX II prototype to Bg singlets and agglomerates. The kill efficiency at the upstream end of the particle collector was extremely high (essentially 100%) while the kill efficiency at the downstream end was somewhat lower (about 97%). This difference is attributed to the higher UV intensity at the upstream end of the particle collector. The down stream kill efficiency can be easily increased to 100% simply by adding a second germicidal lamp module at the exit of the SELEX II prototype. Figure 35 is a chart summarizing the main performance parameters of the SELEX II Breadboard prototype

Bioaerosol Challenge	Run	Surface Inactivation Efficiency (%)			
		Upstream end of removable collection module		Downstream end of removable collection module	
		30 minute exposure	≥ 2.5 hour exposure	30 minute exposure	≥ 2.5 hour exposure
<i>B. atrophaeus</i> (Bg) (Spore as singlets)	1	> 99.9991	> 99.9991 ¹	97.2	98.2 ²
	2	> 99.9996	> 99.9996 ²	95.9	98.6
	3	> 99.9994	> 99.9994	95.5	98.1
<i>B. atrophaeus</i> (Bg) (Spore as agglomerates)	1	99.99	> 99.999	97.2	97.5
	2	> 99.999	> 99.999	97.3	98.0
	3	> 99.999	> 99.999	97.7	97.4

* Note that values denoted as “greater than” are used when no CFUs were detected.

¹Exposure was 3.2 hr.

²Exposure was 3 hr.

Figure 34: Chart showing the surface inactivation efficiency for the SELEX II prototype to Bg singlets and agglomerates.

Total Power Consumption	
With germicidal lamps:	50 Watts
Without germicidal lamps	2.5 Watts
Energy consumption per liter of purified air	
With germicidal lamps	2 Joules/liter
Without germicidal lamps	0.1 Joules/liter
Particle removal efficiency	~ 99% @ 50cfm (for all airborne particle sizes)
Particle kill efficiency	~99.999% (upstream end of collector) ~97% (downstream end of collector)
Pressure Drop	Negligible (open channel)
Inactivation process:	UV germicidal lamps + TiO ₂ photocatalytic coating
Water consumption rate:	~ 5 liters/month

Figure 35 is a chart summarizing the main performance parameters of the SELEX II Breadboard prototype